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ZBLAN Microgravity Study

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1.0 Introduction

With the accession of digital communications, silica based fiber optics production literally exploded in the late 1970's. Today, fiber optic communications is a multi-billion dollar industry with thousands of kilometers of cable installed worldwide annually. However, even before this mass production began, researchers from all over the world began a quest for an even better waveguide with ultra low loss being of paramount importance. This so called "search for the Holy Grail" of fiber optics has led down the path of heavy metal fluoride glasses (HMFG). There are, however, many problems with this family of optical materials.

1.1 History of ZBLAN

Since the discovery of fluorozirconates (a subset of HMFGs) in 1974 by researchers at the University of Rennes, France, [1] there has been a great deal of attention and research focused into their development for commercial applications. After 1980 the vast number of possible formulations has tapered to a very few with practical applications. Formulas from the ZrF_4-BaF_2-LaF_3-AlF_3-NaF (ZBLAN) system demonstrated the greatest promise. This system was first reported by researchers at the Furukawa Electric Co. in 1981 [2] and led to U.S. patent 4,445,755 in May of 1984. Today there are two companies in the United States which are commercially producing ZBLAN fiber. Infrared Fiber Systems and Galileo Electo-Optics are both working with us in this endeavor to commercially produce a superior ZBLAN fiber in the microgravity environment of Earth orbit.

One of the greatest obstacles with ZBLAN is the problem of devitrification. Fluoride glasses have a narrow working range and the viscosity is a strong function of temperature. Rates of nucleation and growth of crystals in the glass depend on the viscosity, making these glasses unstable and prone to crystallization. The viscosity of ZBLAN at the drawing temperature is low, usually between two to five poise, so it is difficult to obtain fibers from their preform melts without crystallization. The preforms usually contain heterogeneous nuclei which grow into microcrystallites above the glass transition temperature, T_g. Since microcrystallites in an optical fiber cause extrinsic light scattering losses of the optical signal, fiber drawing must be completed in a short time to minimize the generation of light scattering centers. To keep these losses to a minimum and to fabricate low scattering loss fibers and other optical components, this research deals with the possibility of minimizing crystallite formation by removing the gravitational influence of solutal segregation of the ZBLAN elements.

1.2 Early work on the KC-135

In April of 1994 a small experiment was flown for the first time on NASA's KC-135 reduced gravity aircraft. During that experiment, fibers of ZBLAN sealed in quartz ampoules were heated above the crystallization temperature (T_x) and then rapidly quenched during the twenty-five seconds of low gravity. Samples were also processed during the high gravity periods of the flight and during normal gravity while on the ground. The results [3] of those samples helped to confirm research performed by the Canadians [4] and many others that the lack of gravity suppresses the formation of crystallites. However, the twenty-five seconds of low gravity provided by the KC-135 does not afford sufficient time to allow for investigations into homogeneous nucleation, only heterogeneous. To investigate homogeneous nucleation, at least two minutes of microgravity is probably required [5]. Without the Space Shuttle, the only way to provide the required length of microgravity time is to use a suborbital sounding rocket.

1.2.1 Details of the Glass Annealing Furnace Experiment on the KC-135

The fiber annealing furnace (FAF) was designed and constructed for use on the KC-135 aircraft. The FAF consists of a preheat furnace, annealing furnace and a quench block. Annealing, in this case, refers to reheating the fiber up to the crystallization temperature, nearly 100°C above the actual annealing temperature. The sample is translated manually through each component using a stainless steel push rod. In operation, a single quartz ampoule is placed at the end of the push rod, and then translated into the preheat furnace for a period of two minutes. This allows the fiber to reach a temperature of 250°C. Then, during the microgravity portion of the aircraft parabola, the ampoule is translated into the annealing furnace for fifteen seconds allowing the sample to reach a temperature of 415°C. This temperature is approximately 20°C above the crystallization temperature of ZBLAN. At the end of fifteen seconds the ampoule is translated into the perforated brass quench chamber. Water is then used to quench the ampoule via a plastic 60 cc syringe. Cooling rates are generally around 40° C/sec.

Two meter lengths of ZBLAN optical fiber were obtained from I.F.S and Galileo. The protective polymer coating was removed chemically, and the fibers were cut into 25mm lengths. Individual fibers were placed in an evacuated quartz ampoule and sealed. Fiber diameters were nominally 300 microns.

Ground tests were performed to determine the time necessary to reach the nucleation temperature and to run 1-g studies. A thermocouple was inserted into a glass ampoule and translated into the preheat furnace until the temperature reached 250°C and then into the annealing furnace until a temperature of 415°C was obtained. In this manner, the times necessary for preheat and annealing during the parabolic maneuver were established. During the KC-135 flights ten samples of each manufacturer's fiber were heated during the low-g portion of the parabola. Actual gravity levels during the twenty to twenty-five second period of low-g range in the 0.01 to 0.001 g level. The processed ZBLAN samples were examined using optical microscopy, scanning electron microscopy and EDX analysis. Those results are published elsewhere[3].

2.0 Development of the ZBLAN Rocket Experiment

The task of designing and fabricating the hardware was started in mid summer of 1995 and was completed by UAH about one month prior to the scheduled flight of Conquest 1. The design was based upon the small annealing furnace which was flown on NASA's KC-135 reduced gravity aircraft. The design was expanded upon to process twelve samples plus one instrumented ampoule simultaneously. In addition it had to operate automatically and collect various temperature data.

Conquest 1 was the mission name for the launch vehicle provided by EER Systems. This mission was also the first suborbital voucher demonstration flight mandated by Congress for procuring commercial launch services. EER was awarded the bid to provide the launch vehicle which they call Starfire I. This vehicle is based on the Thiokol Terrier booster and a Bristol Aerospace Black Brant sustainer motor with the payload segment next in line. Above the payload segment was the telemetry segment, guidance control system, rate control system and finally the parachute recovery section. Figure 1 provides a picture of Conquest 1 taken just after launch on April 3, 1996.

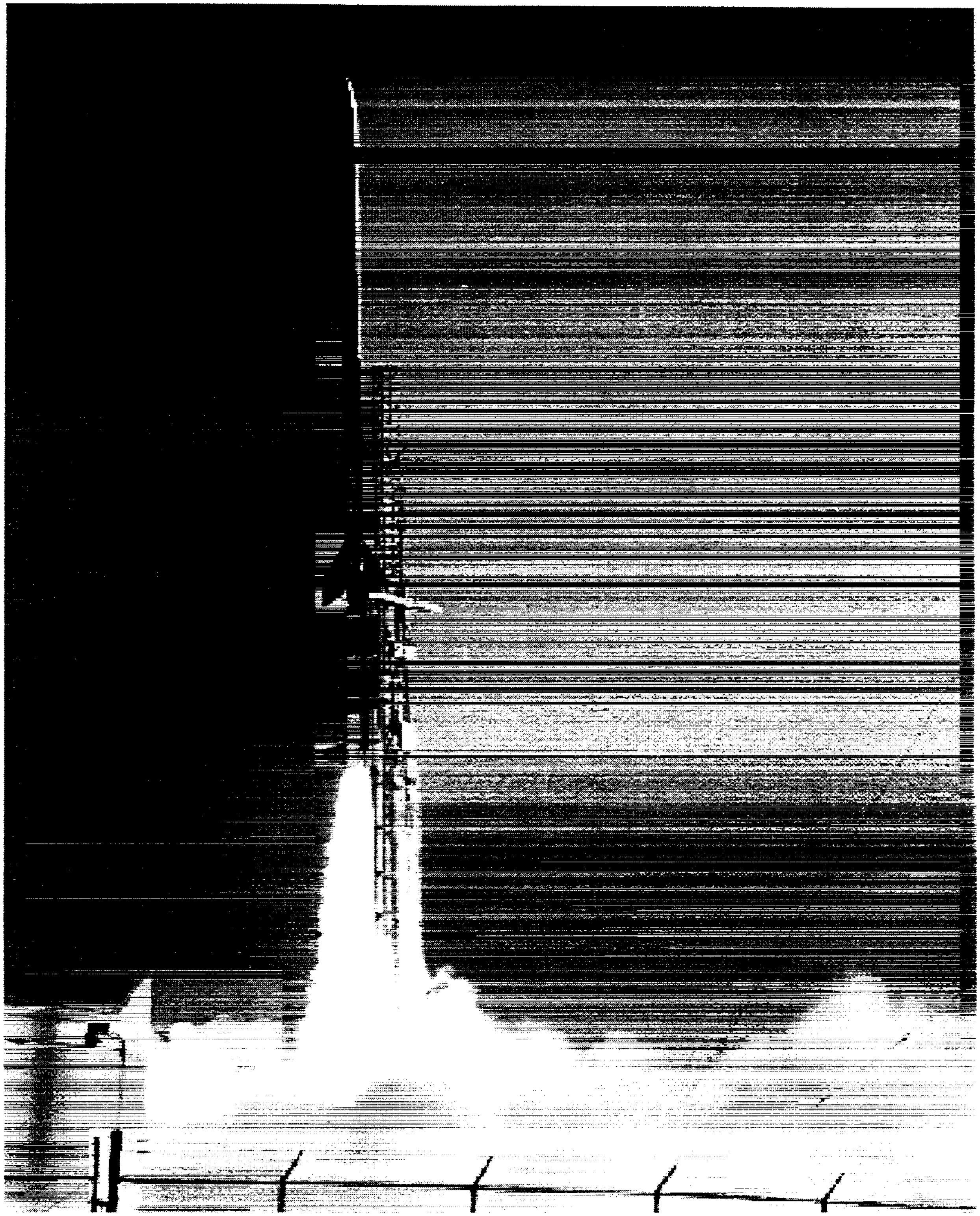


Figure 1. Launch of Conquest 1 on April 3, 1996 with the ZBLAN experiment on board.

2.1 Mechanical Design Process

By mid July, the decision was made that ZBLAN would occupy a 33 inch long payload section. This decision allowed us to proceed with the mechanical drafting of ZBLAN. A total of fourty-one drawings were sequentially submitted to the University machine shop for fabrication. Table 1 gives a listing of all the drawings and the dates they were submitted to the University machine shop. The ZBLAN experiment consisted of six main sub-systems, the furnace assembly, quench assembly, battery assembly, translation mechanisms, temperature control, and flight computer. Figures 1, 2 and 3 below show the complete mechanical assembly of ZBLAN.

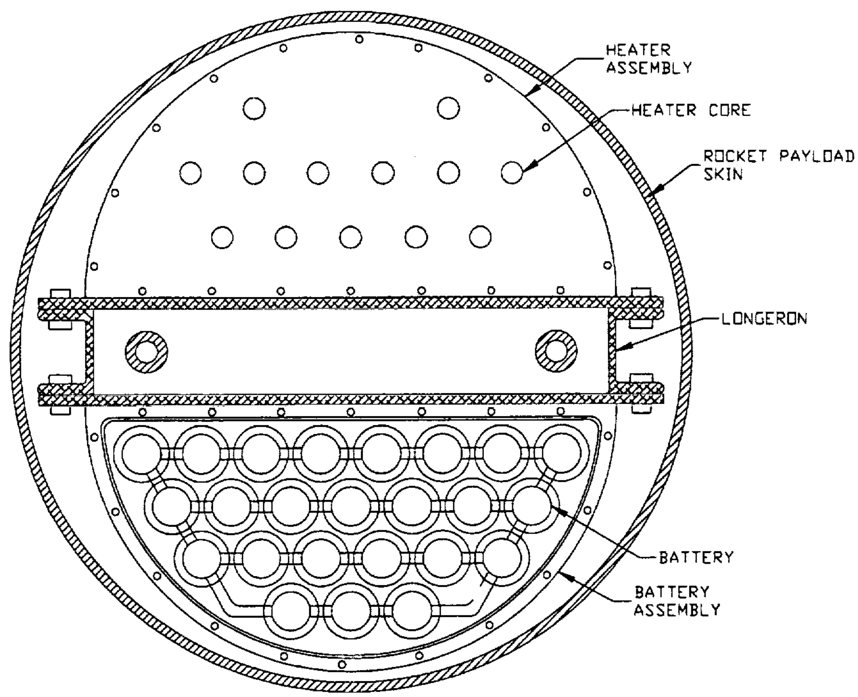


Figure 2. Top view of ZBLAN

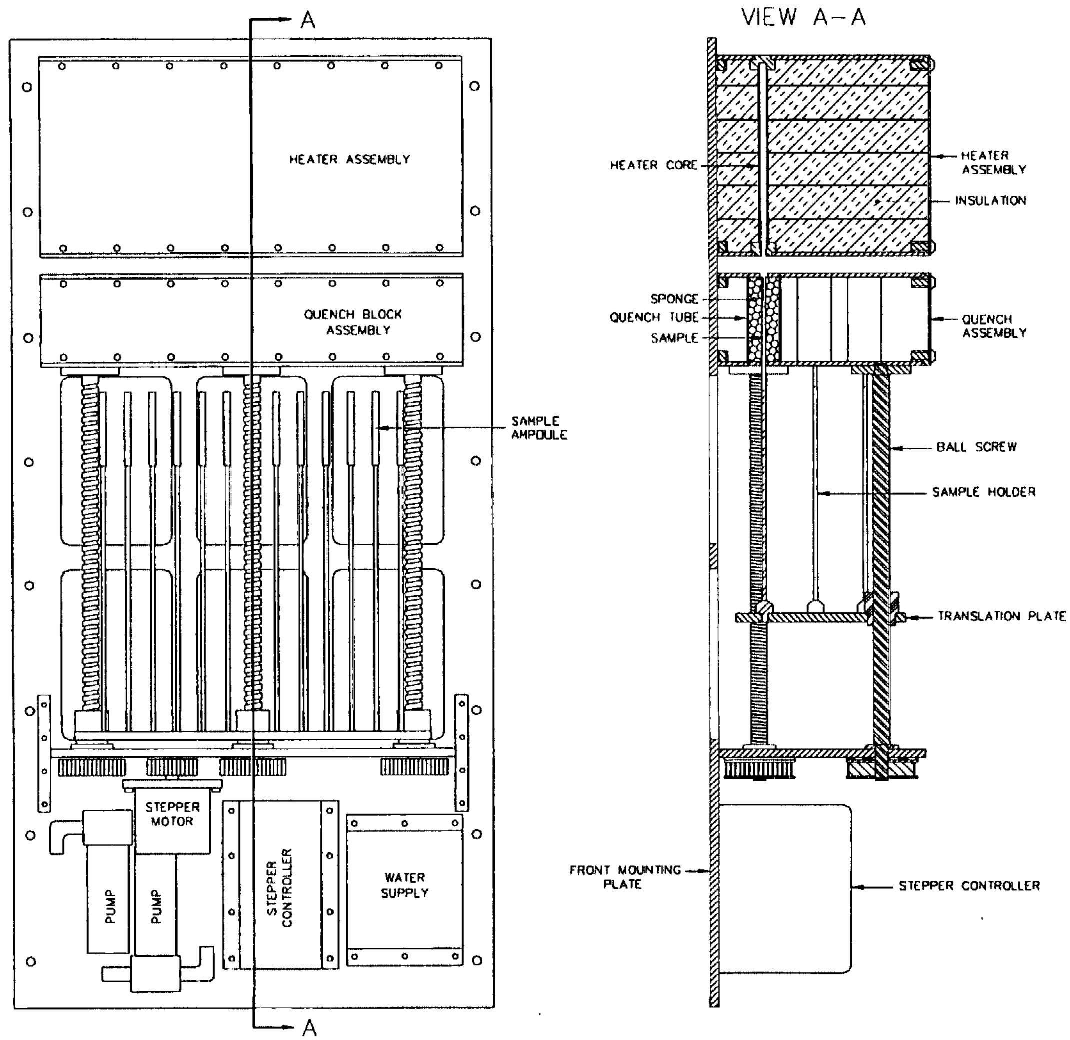


Figure 3. Front payload mounting plate view of ZBLAN

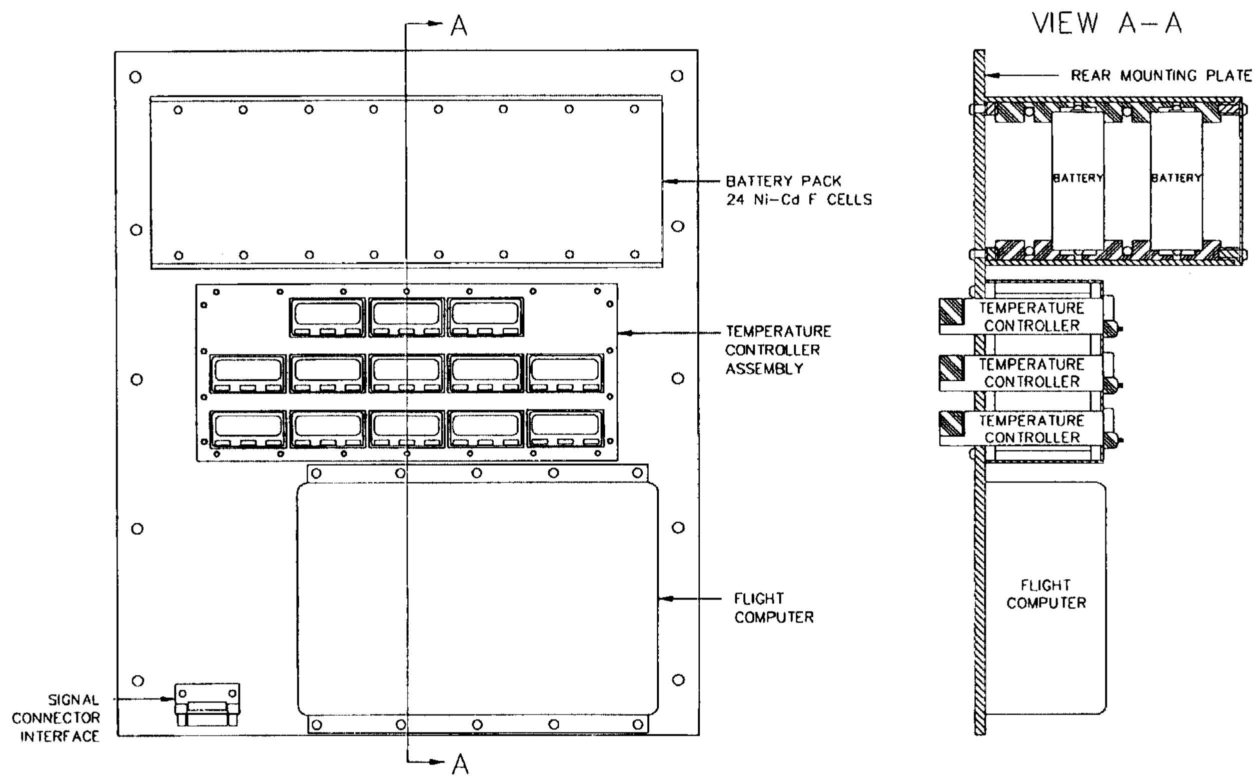


Figure 4. Rear payload mounting plate view of ZBLAN

Complete Drawings	Quantity	Drawing Title	Date Submitted to Shop	Job No.	Complete	Drawn By
ZSPAR-001	2	Payload Mounting Plates	~7/25/95		~8/1/95	S.O.
ZSPAR-002	10	Primary Housing Rib	8/10/95, rev 1 8/23/95	1936	10/16/95	S.O.
ZSPAR-003	2	Primary Housing Supports	10/6/95	2057	10/20/95	S.O.
ZSPAR-004	1	Battery Housing Cover	10/6/95, rev 1 10/19		10/20/95	S.O.
ZSPAR-005	1	Furnace Housing Cover	8/10/1995, rev 1 10/6/95	1994	10/18/95	S.O.
ZSPAR-006	1	Quench Housing Cover	8/10/1995, rev 1 10/6/95	1994	10/18/95	S.O.
ZSPAR-007	2	Battery Top & Bottom Cover Plate	8/10/95; 8/30/95	1994	10/16/95	S.O.
ZSPAR-008	1	Furnace Bottom Cover Plate	9/8/95	2029	10/16/95	S.O.
ZSPAR-009	1	Quench Bottom Cover Plate	8/31/95	2023	10/16/95	S.O.
ZSPAR-010	4	Battery Mounting Block	~8/15/95	2003	10/16/95	S.O.
ZSPAR-011	4	Lead Screw Modifications	10/11/95	2063	~10/23/95	S.O.
ZSPAR-012	4	Pillow Blocks	9/11/95	2032	9/19/95	S.O.
ZSPAR-013	1	Quench Top Cover Plate	8/31/95	2024	10/16/95	S.O.
ZSPAR-014	1	Sample Mounting Plate	9/7/95		10/18/95	S.O.
ZSPAR-015	1	Bearing Plate	9/11/95	2031	10/16/95	S.O.
ZSPAR-016	4	Motor Mount Standoff	9/15/95	2035	~10/18/95	S.O.
ZSPAR-017	2	Support Gussets	9/19/95	2037	10/16/95	S.O.
ZSPAR-018	15	Heater Core Bottom Supports	9/26/95	2045	10/20/95	S.O.
ZSPAR-019	2	Temp Cont. Box Front Frame	10/10/95	2061	10/26/95	S.O.
ZSPAR-020	2	Temp Cont. Box Back Frame	10/11/95	2066	10/26/95	S.O.
ZSPAR-021	4	Temp Cont. Box Side Supports	10/11/95	2065	10/26/95	S.O.
ZSPAR-022	1	Temp Cont. Box Front Panel	10/6/95	2058	10/30/95	S.O.
ZSPAR-023	2	Temp. Cont. Box Side Panel	10/6/95, rev 1 10/10/95	2056	10/26/95	S.O.
ZSPAR-024	2	Temp. Cont. Box Top/Bottom Panel	10/10/95	2062	10/23/95	S.O.
ZSPAR-025	15	Ampoule Holder	10/11/95	2064	10/30/95	S.O.
ZSPAR-026	4	Timing Belt Pulleys Modification	10/11/95	2067	10/12/95	
ZSPAR-027	15	Quench Tube	10/13/95		11/2/95	G.S.

Table 1. A listing of ZBLAN drawings submitted to the University machine shop.

Complete Drawings	Quantity	Drawing Title	Date Submitted to Shop	Job No.	Complete	Drawn By
ZSPAR-028	15	Sample Rod Stabilizers	10/17/95		11/4/95	S.O.
ZSPAR-029	1	Front Mounting Plate	10/20/1995,rev. 1 11/6/95		~10/30/95	G.S.
ZSPAR-030	15	Heater Core Top Support	10/17/95		10/31/95	S.O.
ZSPAR-031	1	Rear Mounting Plate Holes				G.S.
ZSPAR-032	6	Teflon Pulley Spacer	10/20/95		11/2/95	S.O.
ZSPAR-033	27	Quench Tube Fittings	10/30/95		11/8/95	S.O.
ZSPAR-034	2	Zero Box Mounting Brackets	11/7/95		11/13/95	S.O.
ZSPAR-035	2	Water Pump Mount	11/7/95			S.O.
ZSPAR-036	12	Stepper Module Standoffs	11/14/95			S.O.
ZSPAR-037	28	Quench Tube End Plate	11/14/95			S.O.
ZSPAR-038	1	Rod Stabilizer Thermocouple Feedthrough				S.O.
ZSPAR-039	4	Dual Hose Clamp				S.O.
ZSPAR-040	1	Heater Core Casting Mold				G.S.
ZSPAR-041	16	Heater Core Ceramic Cylinder	2/14/96			S.O.

Table 1 (Continued). A listing of ZBLAN drawings submitted to the University machine shop.

The complete design and fabrication process took a little over six months and was completed by early February 1996. The following paragraphs give a full description of the mechanical design process for each sub-system of ZBLAN.

The first step was to draft the payload mounting plates. Once the payload mounting plates were fabricated work began on the primary housing rib, drawing number ZSPAR-002. See figure 5 below.

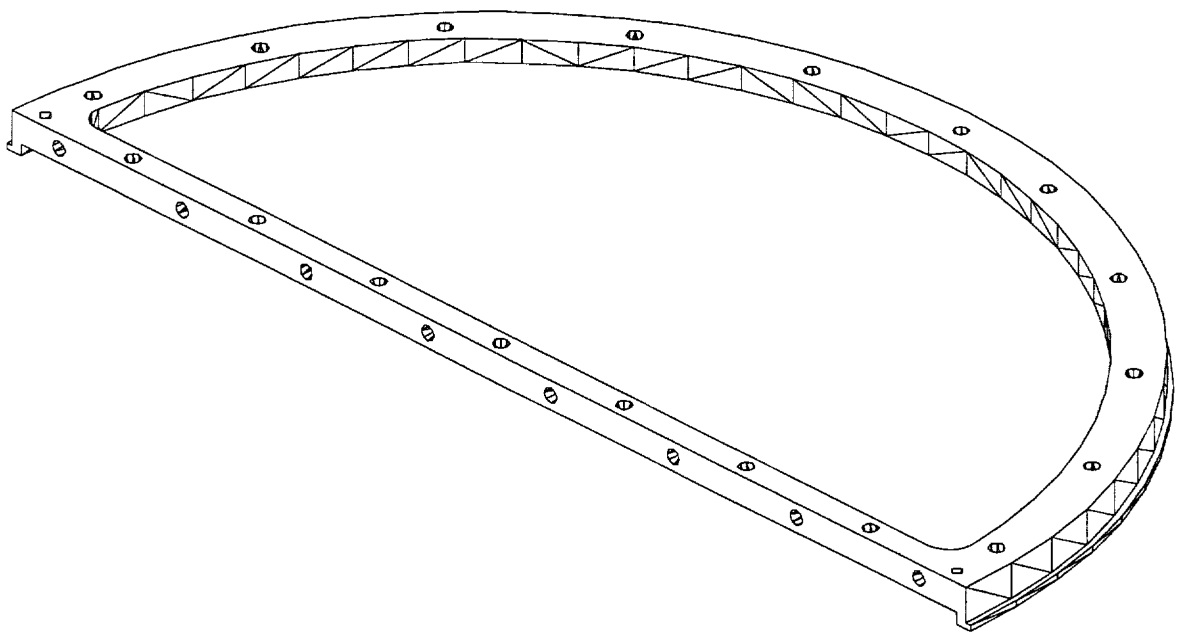


Figure 5. Drawing number ZSPAR-002 primary housing rib

The primary housing rib was designed to be a universal support structure for the heater assembly, quench assembly and the battery housing. The rib was optimized to be light weight but still have structural strength and to accommodate the maximum number of heaters. The final configuration of the rib was a semi-circle with an overall radius of 6.375 inches. Eight #10-32 stainless steel screws held the rib to the payload mounting plate. The rib accommodates thirteen heaters, twelve of which contained ZBLAN samples and the thirteenth an instrumented ampoule.

The design continued with the drawings to complete the heater, quench, and battery assembly shells. Each sub-system required housing supports, top, bottom and outer covers. The housing supports were four rods that were placed vertically in between two ribs to add structural integrity and ease of assembly. The heights for the furnace and quench assembly were calculated by compromising between the sample lengths and overall space available. The height of the battery assembly was determined by the specifications for a F cell Ni-Cd battery. The overall heights for each assembly were 6.00",2.75",4.25" for the furnace, quench and battery assembly, respectfully.

Once the overall available height for the furnace and quench assembly was determined, the inner components were designed. The furnace assembly consistsedof a ceramic core that the Kanthal heater wire was wrapped on, lava stone heater support mounts for the top and bottom of the core, two thermocouples and the assembly potted with Ceramacast 576. Each heater core was instrumented with two type K thermocouples, one for the CAL temperature controllers and one for the flight computer's A/D board. Not only did this enable us to record the temperature data of the heater, it was also a safety measure to insure that if there was a thermal run away of a heater the system could be shut down. Each heater consisted of a ceramic core wrapped with Kanthal grade A nichrome wire. The bottom lava stone cap was designed with a bevel to guide the ampoules into the furnace assembly. A 0.156 inch hole was drilled 0.125 inches deep into the bottom lava cap and a 0.25 diameter hole 0.2 inches deep was drilled from the other end, giving the part an overall length of 0.425 inches. In assembly, the bottom lava cap was placed in one of the holes of the bottom furnace plate. The ceramic core was then set down into the 0.25 inch hole of the lava bottom cap and the 0.156 inch hole allowed passage of the ampoule. The top lava cap only had the 0.25 inch hole 0.2 inches deep for support of the ceramic core. It did not have a hole all the way through it. See figure 6 for the construction of the heater core. When all thirteen heaters were placed within the furnace housing, layers of insulation and fiberglass blankets were packed between and around all of the heaters. The quench assembly consisted of thirteen brass tubes that had inlet ports at the top and bottom of the tubes, brass end plates, household sponges, water bladder, and two small gear pumps. Inside each brass tube housed a standard household sponge that was cut to be a tight fit inside of the tube with a small hole drilled though the center of the sponge to hold and quench the samples. The quench assembly had two functions during flight. It served not only for quenching but also as a cushioned holder for the samples during take-off and re-entry of the payload to prevent breakage of the glass ampoules. The sponges were slightly dampened before take off and immediately saturated with water with the water pump system when the samples were translated into the furnace assembly. The quench tubes were connected in a parallel fashion using 0.125 inch tygon tubing. Two small gear pumps were used on the system, each pump having a separate inlet port on the quench tube. This ensured full saturation of the sponges even if one pump failed. Each pump moved the water from the water bladder and teed off to one of the inlet ports of all thirteen quench tube, one pump using the top inlet port, the other pump using the bottom port. One of the complex problems of the quench system was finding a water bladder that held the proper amount of water and that compressed as the water was pumped out. After extensive searching, it was discovered that a stand hospital IV bag could be modified to the proper size, resealed and still maintain structural integrity under the forces seen in take-off. For added strength, the bladder was placed inside an off-the-shelf extruded aluminum box, then filled with an expanding foam. This insured that the bladder was securely positioned inside of the housing and could not move during the 12-g's experienced during the launch.

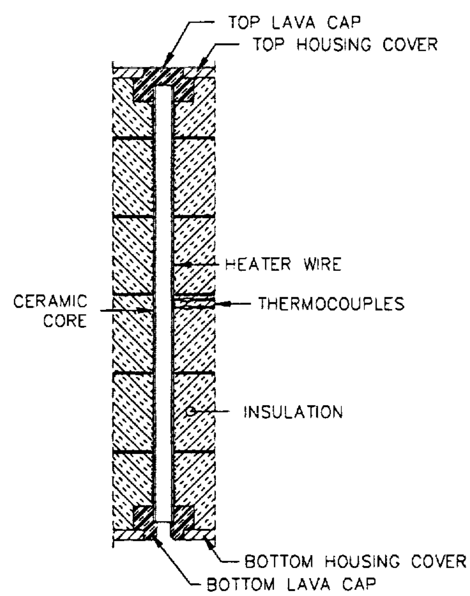


Figure 6.
Cross sectional view of a heater assembly.

The battery assembly was designed to accommodate the maximum number of Nickel-Cadmium F cell batteries within the size constraints of the primary housing rib. The design allowed twenty-four batteries that were held in place with two Teflon mounting blocks. By wiring the batteries in series we achieved 28.8 volts and 8000 milliamp hours for the entire battery pack, which was the desired power required for ZBLAN, therefore, only one battery pack was necessary. The temperature of the batteries was recorded with a surface mount thermocouple attached to one cell to help insure the safety of the batteries. Flight qualification testing of the two battery packs included deep charging and discharging a minimum of five times with the voltage, current and battery temperature histories recorded on a six channel strip chart recorder. During one of the tests a bad cell in battery pack 1 was discovered to be over-heating and was replaced.

Work progressed simultaneously on the translation system and sample mounting. The main translation system components were three lead screws, bearing plate, stepper motor, timing belt pulleys, bearings, and the sample mounting plate. Off the shelf components were used for most of the translation system with minimal modifications. The lead screws were standard Acme threaded shafts with a 5 mm pitch purchased in 4 foot lengths. The shafts were cut to 12.643 inches and mounting adaptations machined on the ends to fit our application. Radial bearings were mounted into the designed pillow blocks and then attached to the bottom of the quench plate. A lightweight bearing plate was designed that maintained structural integrity under the given loads. The design included support gussets on either side of the plate to prevent any flexing while under loading conditions seen during take-off, translation or re-entry. The final design is pictured below.

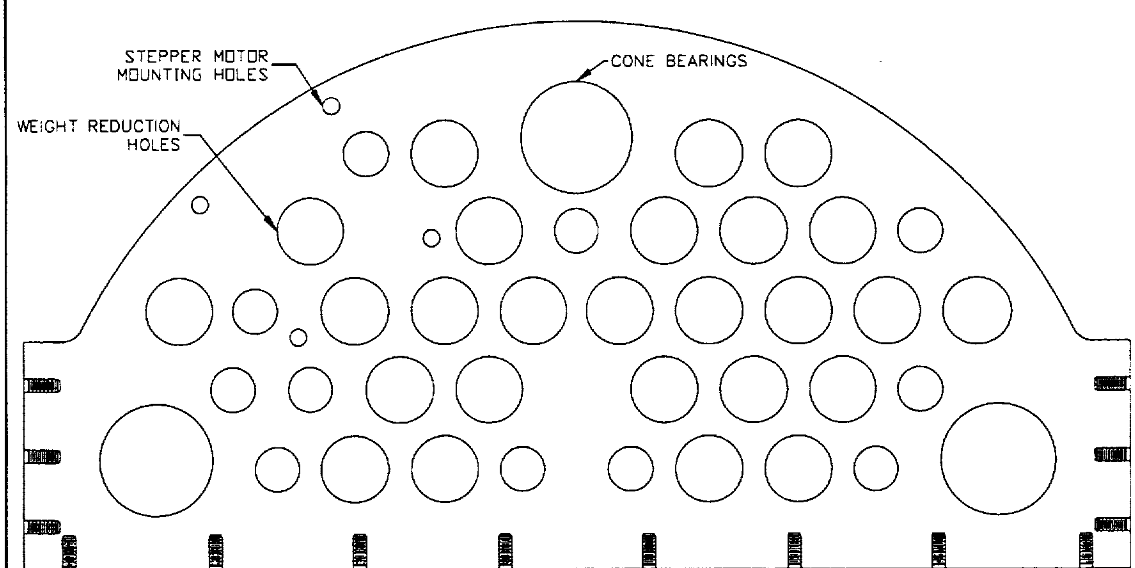


Figure 7. Bearing mounting plate

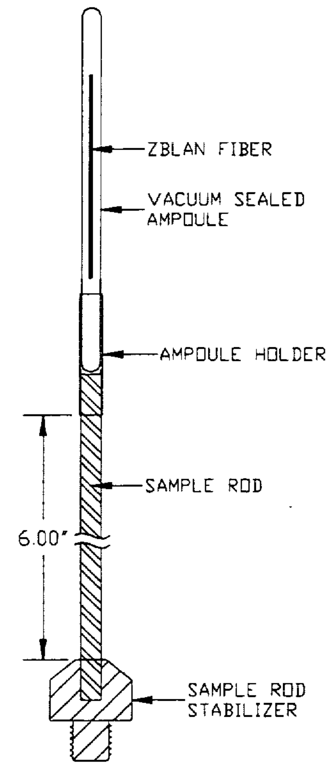


Figure 8. Cross sectional view of the sample mounting assembly.

The cone bearing, stepper motor, belt tensioners and timing pulleys were mounted to the bearing plate. Due to size restrictions, plastic thread mount supernuts were mounted to the sample mounting plate to allow translation of the samples. The samples were attached to a stainless steel ampoule holder that was 0.75 inches long with a 0.140 inch outer diameter and 0.120 inch inner diameter. A 0.125 inch hole was machined 0.250 inches through the center to attach a solid 0.125 inch rod. At the end of the 0.125 inch rod a hexagon shaped stabilizer was attached that screwed into the sample mounting plate. Due to the length of the sample rods, stabilization of the sample rods was a concern. Therefore, the sample rod stabilizers were designed. The stabilizer allowed a ¼-20 thread and larger surface area in contact with the sample mounting plate.

Thirteen 1/32 DIN sized autotune temperature controllers were purchased for controlling each of the individual heaters. These controllers from CAL Controls are the smallest 24VDC digital controllers presently available on the market. Due to size constraints, a five sided box was designed to house the controllers. The design of the box recessed the controllers into the rear mounting plate. By milling individual holes in the rear mounting plate for each controller, the plate acted as a support structure for the back of the temperature controllers. This also allowed the housing for the thirteen controllers to fit within the limited radius of the payload envelope.

The flight computer consisted of a PC-104 386 EX motherboard, 16 bit A/D board, AD595 and custom built thermocouple conditioning, power distribution and solid state relay boards. It was the main control center for the experiment. It powered the ZBLAN experiment, controlled the power of the heaters, the stepper motors, translation system, and water quench system and stored the temperature data for the thirteen heaters, one sample temperature and battery temperature. All of the custom printed circuit boards and components were mounted in a stacked configuration using aluminum standoffs and housed in an off-the-shelf aluminum box. The CPU and A/D board were shock mounted using rubber standoffs. Angle aluminum was added to the sides of the box for mounting to the payload mounting plate.

The following figures were taken of the complete flight hardware package just prior to leaving for White Sands Missile Range. They provide additional details regarding the hardware assemblies.

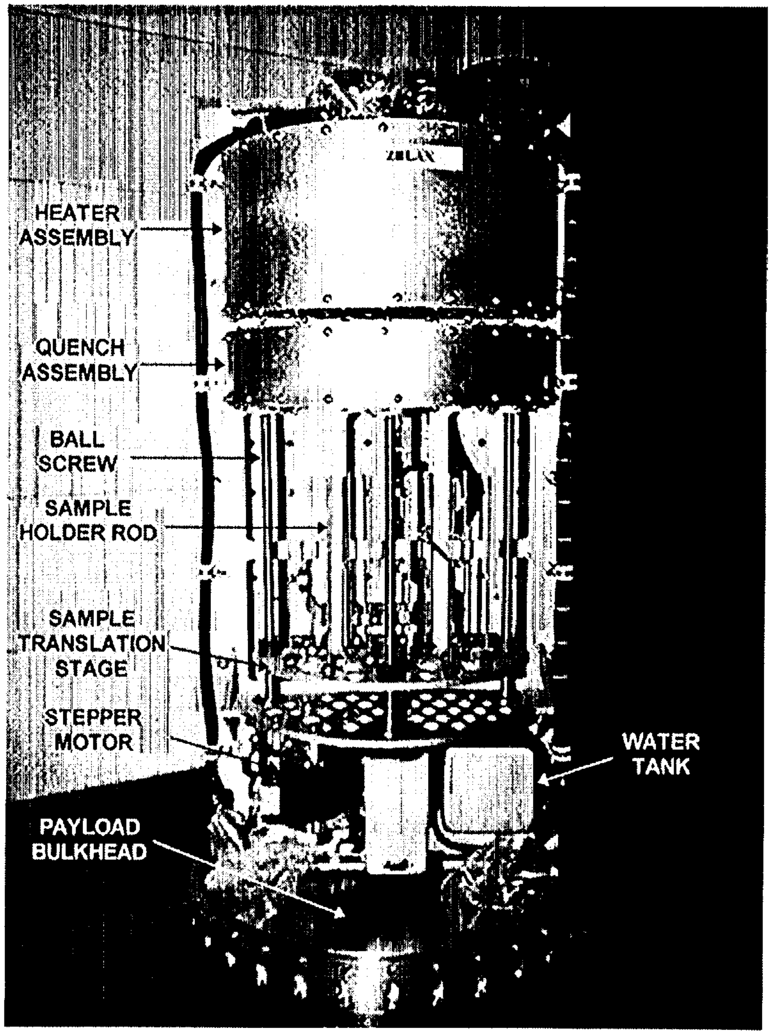


Figure 9: Photograph of the entire front payload mounting plate assembly showing the heater and quench assembly, sample translation system, water pumps, stepper motor and controller housing, and the quench water tank

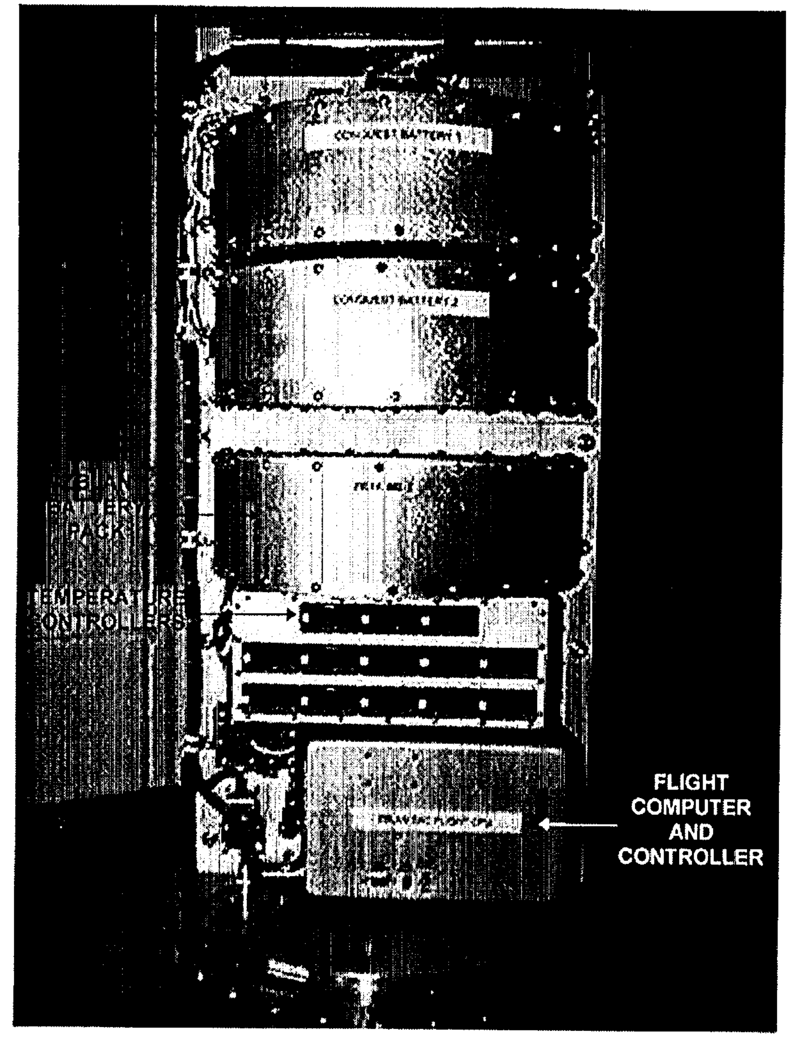


Figure 10: Photograph of the entire rear payload mounting plate assembly showing the battery pack, temperature controllers, and flight computer assembly. The two upper battery packs were used to power the other experiments in the rocket.

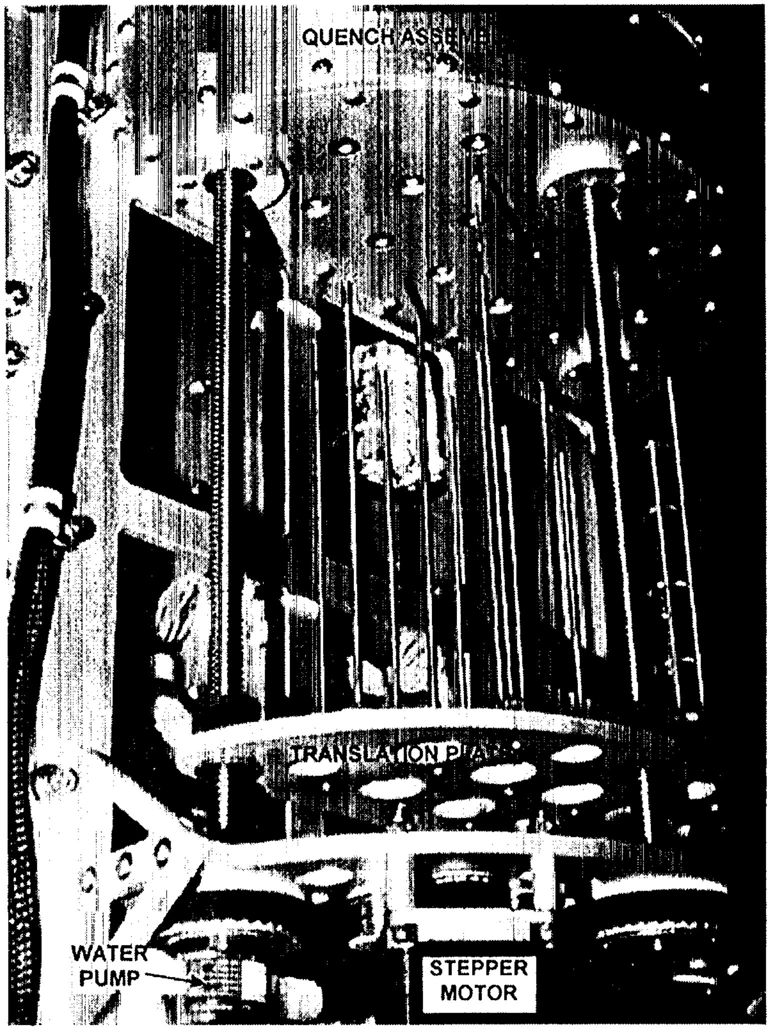


Figure 11: Close up view of the translation stage and sample holders positioned to enter the quench assembly.

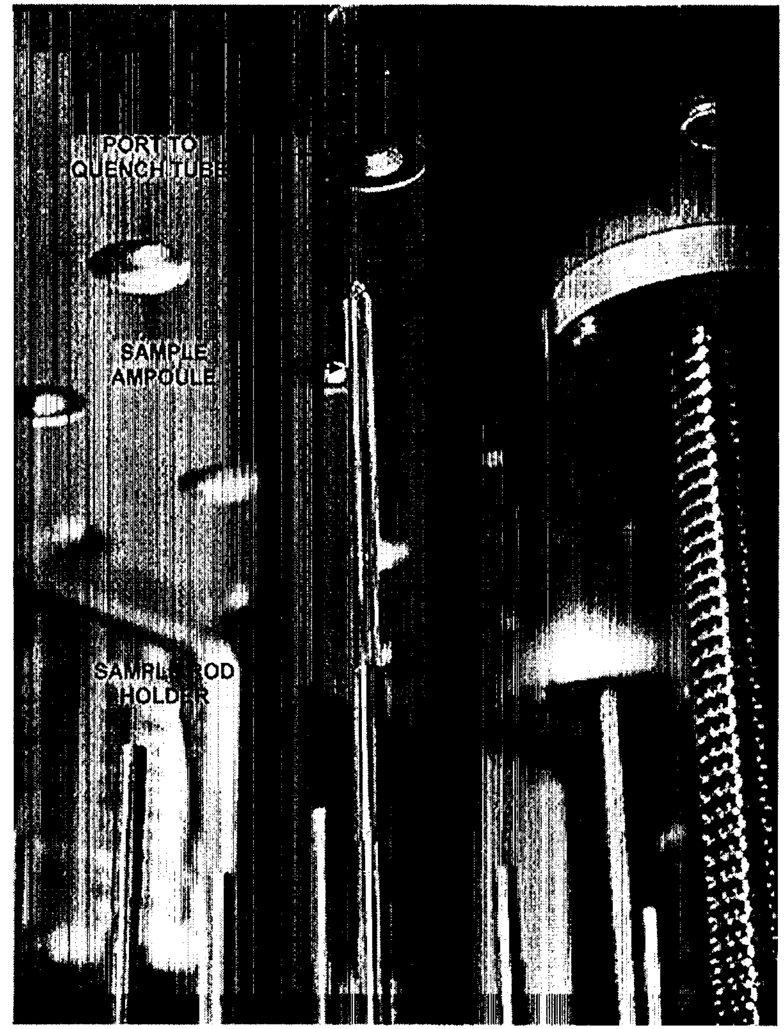


Figure 12: Close up view of the quartz ampoule located in the end of the sample holder rod.

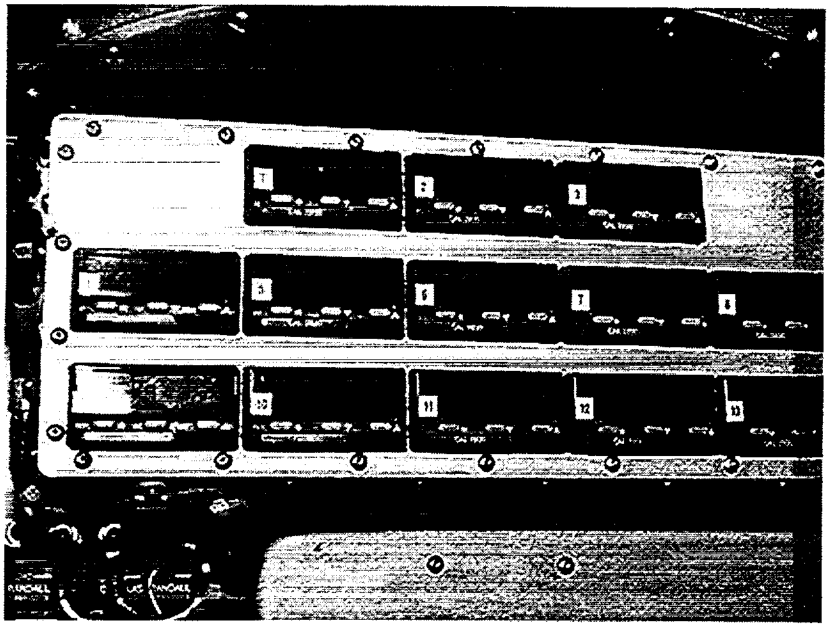


Figure 13: Close up view of the CAL model 320.050 temperature control assembly. Each of the thirteen PID controllers was set to 0.1°C resolution for type K thermocouples.

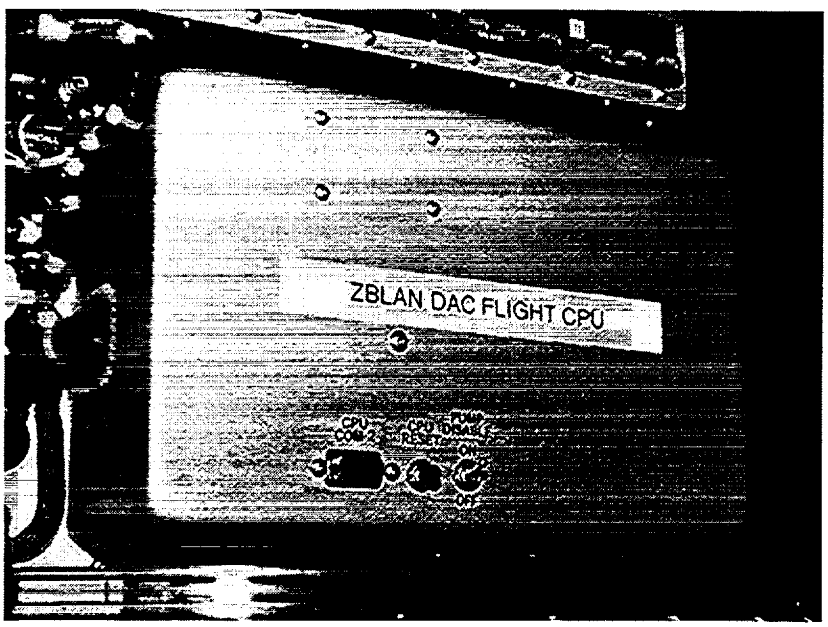


Figure 14: Close up photograph of the flight computer housing. Inside are contained the 386 CPU, 16 channel A/D board, power distribution, and control boards.

2.2 Electronics

In order to meet the timeline of start to finish construction in 6 months the electronics were kept to a minimum. Everywhere possible, off-the-shelf hardware was used to keep development time low. This included the thirteen temperature controllers, computer and data acquisition boards, solid state relays for controlling power, and the stepper controller system. There were only two custom designed and fabricated printed circuit boards required to complete the electronics subsystem. One board provided power distribution to each heater circuit and other circuits as well and provided fused protection for each circuit. The other board was used to mount the optical isolators, solid state relays, and thermocouple signal conditioning. Figure 15 provides a general electrical schematic of the ZBLAN experiment.

2.2.1 CPU and A/D

The flight computer was comprised of two 3.55" by 3.77" sized PC-104 format boards purchased from Micro/Sys Inc. (818-244-4600). The CPU card is a SBC1386EX model using a 32 bit 80C386EX CPU that is Intel compatible. It provides one megabyte of RAM, 512K of flash EPROM, two serial ports, three 16 bit counters, a watchdog timer and battery backed real time clock, and three parallel I/O ports with ten lines uncommitted. To make the CPU board appear as an IBM PC running in DOS, a firmware program called RUN.EXE was installed at the top of flash memory. When powered up this firmware initializes the registers and sets up the environment for the application program. To power the board only 5 VDC at 150 ma is needed in this application. When reprogramming the EPROM a 12 VDC supply is needed.

The analog to digital converter used is an Analogic model AIM16, 16 bit, 16 differential input channel board. It is set up for measuring 0 to 5 volt input signals (unipolar) from the fifteen AD595 thermocouple amplifiers and the battery voltage signal after it has been passed through a voltage divider. The onboard amplifier gain is set to 1. After testing it has been determined that the multiplexer has an inherent problem with crosstalk between certain channels. While this did present a problem with the data, a solution was found to subtract out the error.

2.2.2 Power Distribution and Control Boards

To complete the necessary power distribution, fusing and control functions, two custom designed boards were fabricated in-house. Using Tango PCB software to generate the artwork, a novel method was employed to output the artwork using a standard laser printer. This method of producing artwork without the need of expensive photoplotters is being submitted as a NASA tech-brief. Once the artwork was completed the boards were exposed and etched using traditional positive photoetching techniques. The power distribution board provided the main bus routes for the thirteen heater circuits with each one fused individually and a mounting surface for the two DC/DC converters and power filter.

2.3 Software

The ZBLAN software was cross compiled for the 386EX single board computer on a 486DX PC under Microsoft Visual C 1.00, running under Windows with the target environment set to DOS. Other compilers used in the early stages of development, namely Turbo C and Borland C 3.0, were found to be catastrophically unstable when used with the very large data

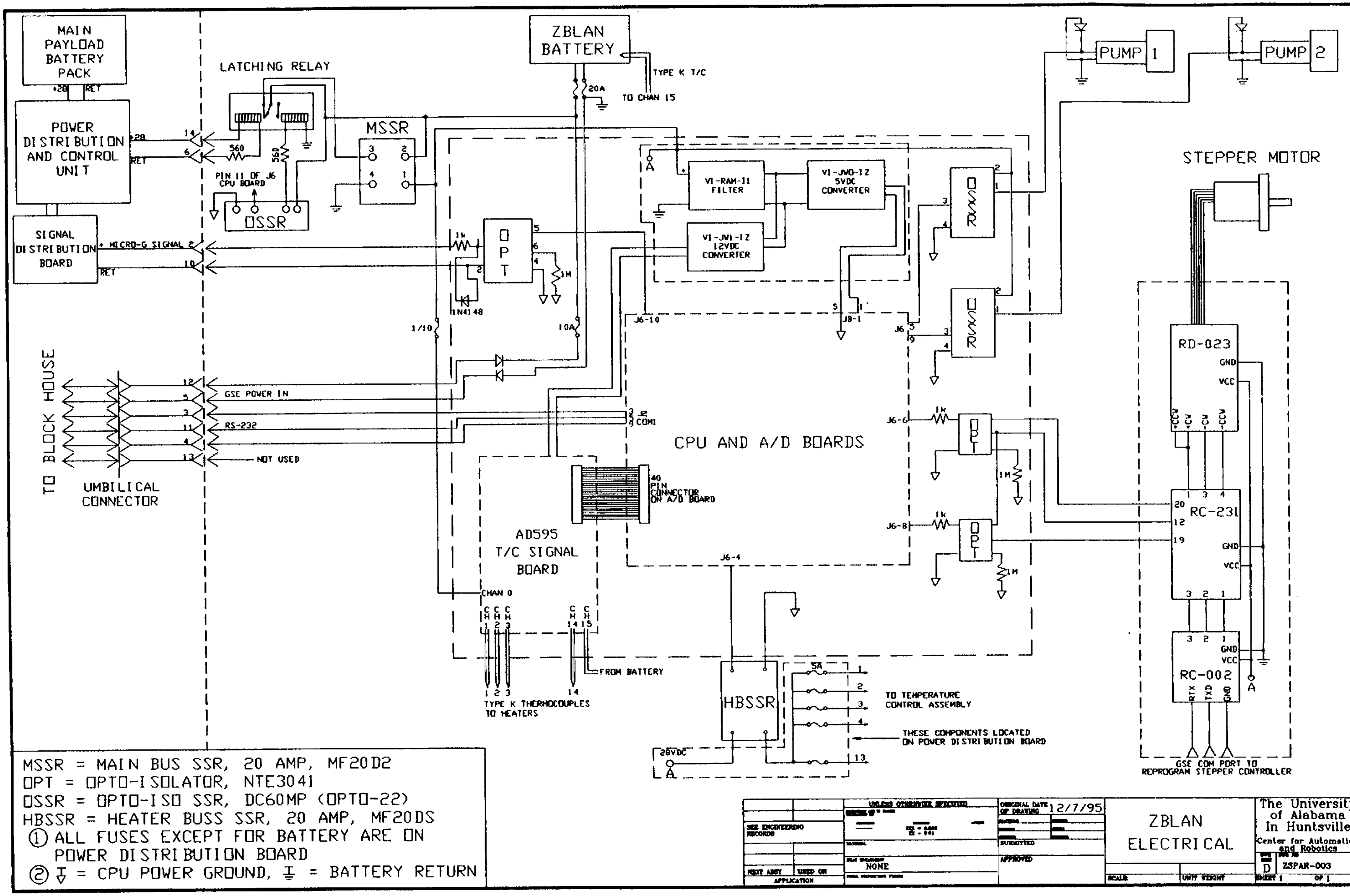
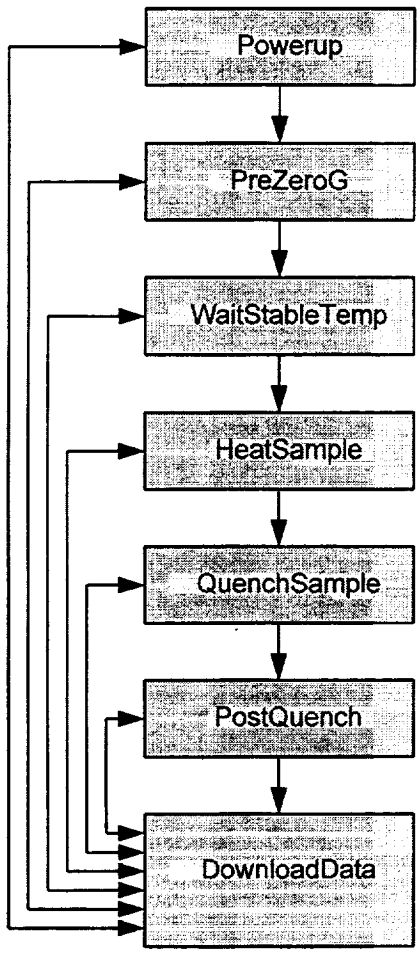


Figure 15. A general electrical schematic for the ZBLAN experiment

structures found in the ZBLAN software. These data structures were used to store all of the temperature data.

The operation of the ZBLAN software is simple. Software emulates a simple state machine, manages data collection and logging, sends motor and pump control signals, and provides a simple user interface for data downloading and testing. The following diagram shows the state sequence and transition criteria.

Software Flow Diagram



State	Entrance Condition
Powerup	System Start
PreZeroG	Initial Setup Complete
WaitStableTemp	ZG signal from control computer
HeatSample	Temperature Stable, or time-out
QuenchSample	Program Timer
PostQuench	Automatic
DownloadData	Data Space Full, or user interrupt

The values used to control data logging intervals, temperature levels, and time-out values are stored in SBC.H and can be modified at compile time.

The CPU board manages the A/D board through a 16 bit PC/104 bus connection, allowing full program control and a wide data path for sample data. On board the A/D board, the controller is set to take 256 samples (16 from each of its 16 input channels) and store them in its sample FIFO (First In/First Out) at a program defined interval controlled by setting a countdown timer. When the FIFO is sufficiently full, the CPU reads. the sample data across the PC/104 bus from the sample FIFO to program data storage space, where the data is averaged to provide one sample per channel.

Using on-board control lines, the CPU uses TTL I/O lines to send signals to the Stepper Motor Controller (a programmable, intelligent module), a heater enable/disable control, and the quench pumps. One TTL I/O line is also used to poll for the zero-g signal from the flight control computer. The assignments and names for these lines are shown in the following table and set in the header SBC.H.

When the flight computer receives the zero-g signal from the main payload computer the program will test the stability of the thirteenth heater core. If it is with tolerance, the command to begin sample translation will be given. Otherwise, the program will wait for a stable temperature. However, if the waiting period exceeds 45 seconds then, a time out occurs and translation will begin anyway.

2.3.1 Reprogramming the Flight Computer

If the user desires to change any of the program constants stored in SBC.H or modify program behavior beyond on-line configuration, it is necessary to recompile and download the new executable software into the flight computer's on-board EEPROM.

Steps:

1. Enter the Visual C Environment and open the SBC (Single Board Computer) project.
2. Make changes required to SBC.C MAIN.C and SBC.H.
3. Scan all dependencies.
4. Rebuild all.
5. Exit Visual C
6. Connect the LOAD connector to PORT B of the flight computer and to an unoccupied serial port of your PC.
7. Start up a terminal emulator and set it for the appropriate serial port, 19200 baud, 8 bits/word ,1 stop bit, and no parity.
8. Ensure that +12V is available to the flight computer (in addition to the normal +5V).
9. Power up the flight computer.
10. You should immediately see a message in the terminal window. If not, power off the flight computer, recheck all connections, power to the flight computer and your terminal settings. If this does not clear up your problems, seek qualified assistance.
11. The flight computer should prompt you for confirmation on erasing flash EPROM. Confirm the erasure.
12. If erasure fails, odds are the +12V input to the SBC is the fault. Recheck this voltage and make sure it is properly connected. If after restart the problem persists, seek qualified assistance.
13. After erasure, the flight computer will prompt you to download the new executable. Using your terminal emulator, locate your new executable (it should end with a .EXE) and send it to the flight computer using the XMODEM protocol.
14. After Download, turn off power to the flight computer and disconnect the LOAD cable.
15. The flight computer is now upgraded and ready for operation.

Note: DO NOT modify the existing code unless you understand its operation and know what you are doing. A single, inappropriate change could EASILY lead to experiment failure.

2.3.2 Downloading the Data

After an experiment run the data collected by the flight computer can be downloaded using any terminal program and a PC or laptop. The following provides the basic steps necessary.

1. Connect the laptop to the ZBLAN experiment via the ZBLAN GSE interface box and serial cable. Power up the laptop and excute a terminal program with the communication parameters set to 19200 baud, 8 bits, 1 stop bit and no parity.
2. Power up the ZBLAN experiment using the ZBLAN GSE box ENABLE switch.
3. A sign on message will appear on the laptop screen.
4. Hit the "-" sign to turn off the heater bus.
5. Hit Control "D" to interupt the program. A user menu will appear.
6. Set the terminal program to begin reading and saving the experiment data to a file.

7. Hit "P" to download the pre-heat sample data and "Z" to get the heat up, soak and cool down temperature data.
8. After download is complete hit "O" (not zero) to open the main power relay and thus power down the experiment hardware.

3.0 Preparations at White Sands Missile Range

The following provides an account of the activities required to prepare the ZBLAN hardware and the overall payload segment and launch vehicle for flight.

The integration of the last major subsystem, the furnace assembly, was finished just in time to perform a series of tests on the fully assembled experiment. No problems were found during these tests. It was concluded that the ZBLAN experiment system is functional as an integrated unit. Fine tuning of the temperature controllers and thermocouple calibration tests had to be performed out at White Sands Missile Range.

3.1 Integration Activities

March 1: All the backup parts, ground support equipment and the ZBLAN experiment system were packed and loaded up in preparation for the trip out to White Sands. The ZBLAN experiment itself was loaded into a specially designed experiment carrier. At 5:30 a.m. on March 2, the UAH integration team left UAH in four vehicles transporting all the payload and ground support hardware to White Sands.

March 4: Arrived at WSMR and unloaded the trucks at the Vertical Assembly Building of Launch Complex 36. The integration team began setting up the work areas for the different experiments.

March 5: The ZBLAN experiment and support equipment was unpacked and inspected for any damage that might have occurred during the trip. No signs of any damage was noted.

March 6: ZBLAN system was assembled and powered up for a functional test. Everything worked as required. Work then turned to stacking all payload sections vertically and measuring the radial run out of the assembled payload segment. Results were within tolerance.

March 11: The payload section assembled for vibration testing.

March 13: Moved the assembled payload section to building 300K for the vibration test.

March 14: The vibration test was conducted. The payload 28VDC power wires were accidentally shorted to the payload case during the test. This short is suspected of contributing to subsequent erratic operation of the stepper controller on the ZBLAN experiment. The RC-231 controller was later removed and a backup unit installed.

March 15: A bend test of the payload section was performed. During this test a known point force of 1113 lbf was applied to the nose end of the segment and the amount of segment flexing measured. Results were within tolerance.

March 16: ZBLAN team arrived at the VAB and began work on finishing up on the temperature controller and thermocouple calibrations.

March 17: Finished temperature calibration and other tests on the ZBLAN hardware.

March 18: Concentrated work on getting the PDCU, SDB and GUI electrical systems working on the rocket.

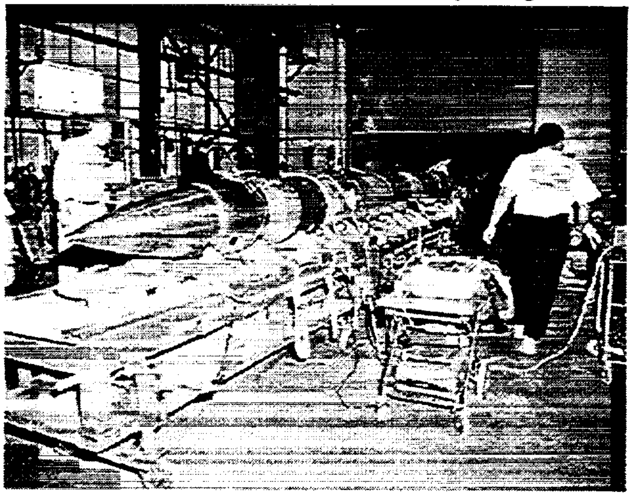


Figure 17. Integration activities in LC36 VAB.

March 19: Due to problems with rocket systems, a one week delay in the launch was called. Efforts continued on getting the PDCU, GUI and SDB electronics working.

March 20 to 26: During this time period most of the effort was devoted to getting the other experiments and hardware operational. Mission Sequence Tests (MST) were begun and ZBLAN performed nominally in all the tests. These tests were performed without the individual payload sections being assembled. Interconnect cables were used for communications between the sections and MSTs performed on the entire payload segment. Testing began on GSE power and RS-232 communications between the block house and the launch rail and finished with no problems encountered for ZBLAN.

March 27: Flight Readiness Review held and final decision made on the countdown procedures. Launch vehicle predicted performances were discussed. No major problems were determined. Readied the payload sections for the horizontal test.

March 28: The complete payload section was assembled for what is referred to as the horizontal test. During this test the entire launch vehicle was assembled not including the first and second stage motors. Later that night, ZBLAN was accidentally turned on when the PDCU was powered up (a "high" pulse occurred which latched the power relay in ZBLAN). The activation was not noticed and as a consequence the experiment was left on long enough to completely discharge the battery. Recharged the battery through the umbilical connector during the night.

March 31: The experiments and payload sections were assembled for the vertical test. By then it was believed that all of the experiments that comprise the total payload section including the PDCU, SDB, and GUI are working.

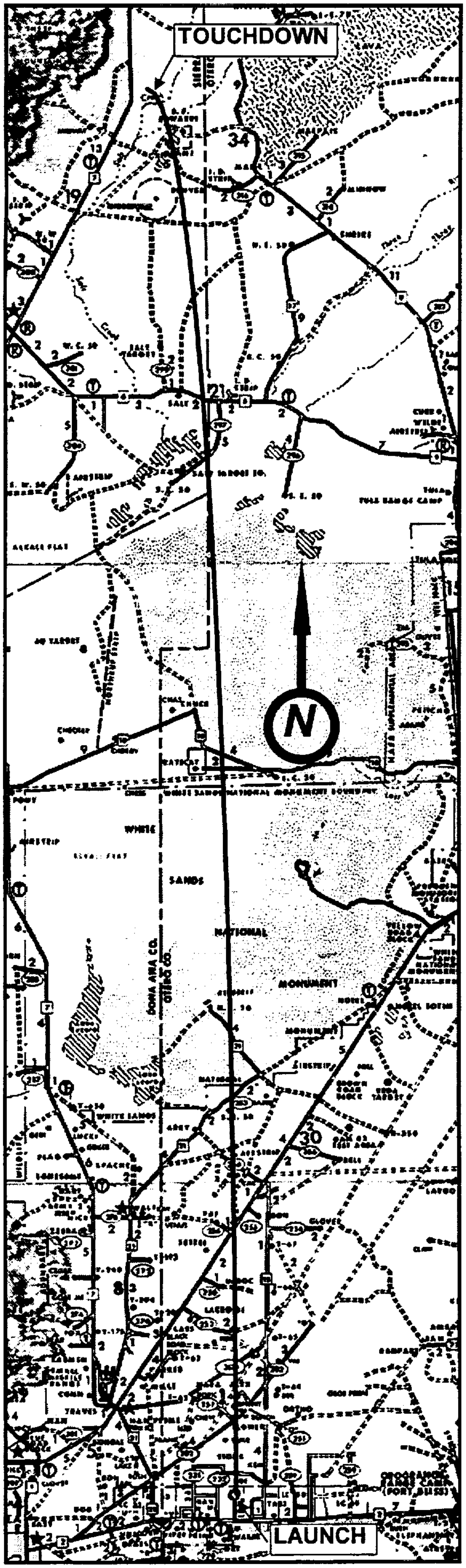
April 1: Preliminary vertical test was performed in the VAB and some minor problems with the FOAM experiment corrected. Then the assembly was transported out to the launch rail and the umbilicals connected. From the block house all systems were powered up and checked in preparation for the launch on April 3. Again minor problems were found and corrected but, overall, the tests went extremely well. ZBLAN worked perfectly throughout the process. When the vertical test was completed the payload section was taken back to the VAB and disassembled. Work turned to final preparations of the experiments for launch. Changes were called in on the temperature setting for the ZBLAN heater cores. The setpoints were changed and temperature checks performed. ZBLAN battery pack was allowed to charge overnight at 800 ma/hour.

April 2: Finished performing last minutes tests on ZBLAN. The twelve samples (six from I.F.S. and six from Galileo) were loaded and positioned into the quench assembly for launch. Work then turned to the assembly of all the payload segments into the final flight configuration. Other integration crews handled the guidance, telemetry, nose, and RCS segment assemblies. Around 7:00 p.m. the final assembly was complete and the entire payload section was transported out to the launch rail. After the section was mounted to the motors and umbilical connections made, system testing from the block house began. It was then discovered that a major problem existed in that the PDCU would not respond when powered up. Work then focused on finding the cause of the problem and correcting it. Fortunately, the PDCU was located directly behind an access panel on the payload segment allowing easy access for troubleshooting. The problem was corrected around 10:00 p.m. and the successful testing completed by about midnight.

April 3: Arrived back at the block house at 3:30 a.m. to begin countdown procedures. At T-41 minutes ZBLAN was powered up and heating began at T-38 minutes. All systems were nominal until T-0 seconds when a hang fire took place. Due to a noisy AOK signal from the S-19 guidance system the launch panel was prevented from going to full GREEN. A bypass was enabled and a second attempt at launching was begun. Again a hang fire occurred. With another correction in place, the launch occurred about 25 minutes late. After about a 14 minute flight the recovery crew left for the impact point 55 miles down range using two Army helicopters. Data from ZBLAN was downloaded onto the laptop for safe keeping. The payload section was broken down into two parts with each one carried back by helicopter to the VAB. See Figures 19 and 20.

3.2 Hardware Operations During the Flight

In the operation of the experiment the flight computer provided all command, control and data acquisition functions. Upon initial power up from an external command signal at T-41 minutes to launch the internal battery supply was latched closed and thus powered up the flight computer. The self booting C^{++} program then took control and began collecting temperature data. The heater bus can be toggled off and on by hitting a "-" or "+" key on the laptop in the block house. At T-38 minutes the "+" key was hit to begin heating. Subsequently, the temperature controllers were powered up and began heating the thirteen heater cores to the predefined setpoints. For the flight, four sets of three controllers each were set to 323°C, 340°C, 363°C and 374°C respectively. The thirteenth controller, used for the instrumented ampoule, was also set to 374°C. During the prelaunch countdown, ground support power was provided to initially heat the cores up to temperature and conserve battery power. This was started about ten seconds after the heater bus was toggled on. At T-2 minutes to launch the ground power was removed and the experiment switched to internal power provided by the twenty-four F cell NiCd battery pack. Hitting the "=" key on the laptop produced a downlink of one line of temperature data. This was used to confirm the temperature conditions prior to launch and also provided a means of determining the translation plate location. If a premature trigger or false start of the stepper motor had occurred, the instrumented sample ampoule would have indicated a high temperature reading. Fortunately, the false trigger did not happen. During the course of attempting to launch Conquest 1, two separate hang fires prevented the ignition of the first stage. This resulted in the internal ZBLAN battery having to provide power for almost 30 minutes longer than was originally planed. Fortunately, the battery reserve was sufficient to allow for the delay in the launch.



At seventy-seven seconds after launch the primary payload command computer sent a signal to the ZBLAN experiment indicating that the payload was now in microgravity. Acceleration levels were in the 10^{-5} to 10^{-6} g level through the majority of the microgravity period. During times of mechanical processes within the payload, acceleration spikes to 10^{-3} could be observed. After an additional fourty-five second waiting period, to allow for the temperature controllers to restabilize the heaters, the translation mechanism was commanded to move the samples from the quench assembly to the heater assembly. Twenty seconds after the start of the sample translation, the flight computer activated the two water pumps to saturate the thirteen sponges housed in the quench assembly. The pumps were on for another twenty seconds and were turned off before the sample heat soak period began.

Following a five minute heat soak, the translation mechanism was reversed and the processed ZBLAN samples were then retracted very slowly back into the quench assembly. There, the water soaked sponges rapidly cooled the samples and kept them cool during the re-entry phase of the payload. At that point in time the experiment was finished and the flight computer's only task was to continue collecting temperature data. Temperatures measured exterior to the quench assembly reached 209°C during re-entry.

When the payload finally touched down by parachute two Army helicopters were dispatched to the recovery area. The ZBLAN flight data was then downloaded onto the laptop computer. This provided a copy the flight data that could be permanently stored on disk. The payload segment was then split into two sections, loaded onto the helicopters and returned to the staging area at White Sands Missile Range Launch Complex 36. It took approximately two hours to complete this operation.

This map (Figure 18) provides the general launch and impact points located within the White Sands Missile Range. The flight parameters for the vehicle were 175 miles maximum altitude and it touched down 55 miles down range from LC-36.

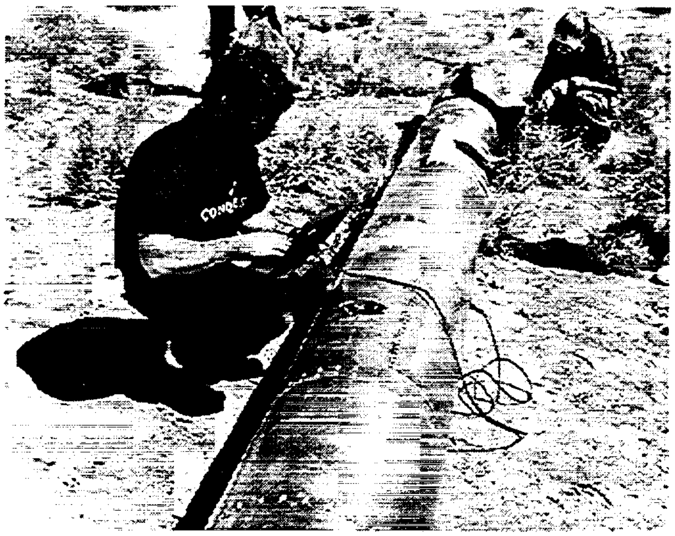


Figure 19. Data from the ZBLAN experiment being downloaded onto the laptop about one hour after launch of Conquest 1. This was performed as a precaution against losing the data due to battery charge failure. Data was downloaded via the signal connection through the umbilical connector on the side of the payload segment. The laptop used the Windows 3.1 Terminal program to communicate with the experiment. It was later learned that because the laptop was operating on battery power the hard drive was not always powered up to store the incoming data. This resulted in the ASCII data format being corrupted at certain points and required some re-formatting before it could be loaded into a spreadsheet program. Since then it has been learned that using a non Windows communication program prevents the data format corruption from occurring even with the laptop operating on battery power.

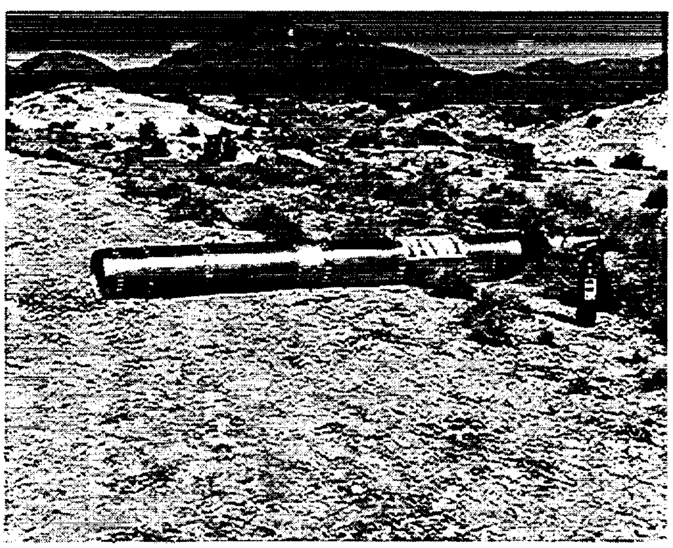


Figure 20. Payload segment impact point in the middle of an old road bed. The segment descended with the tail straight down at approximately 35 mph. Upon impact with the ground, it then fell over pointing almost due east. It is at this time the nine sample ampoules may have been broken due to the sudden lateral force.

4.0 Analysis of the Flight and Ground Results

From an operational standpoint the experiment worked as planned during the flight. It was, however, learned that after recovery of the rocket payload, nine of the twelve sample ampoules had cracked and the ZBLAN fibers were immersed in the water saturated sponges. Failure of the ampoules occurred after the ampoules had been retracted back into the quench assembly and was probably due to the g shock upon parachute deployment or impact of the payload with the ground. This led to rapid water catalyzed crystallization of those samples. The three samples which survived were ones that had been heated to the pulling temperature of 323°C for the two Galileo fibers and 340°C for the one I.F.S. fiber. None of these showed evidence of additional crystallization. Figure 21 is a SEM of one flight processed Galileo sample. Samples heated to the same temperature flight profile on the ground showed some evidence of crystallization as seen in Figure 22. Porosity was found present along the side of the flight processed fibers which was in contact with the ampoule wall. This was seen in all three flight samples.

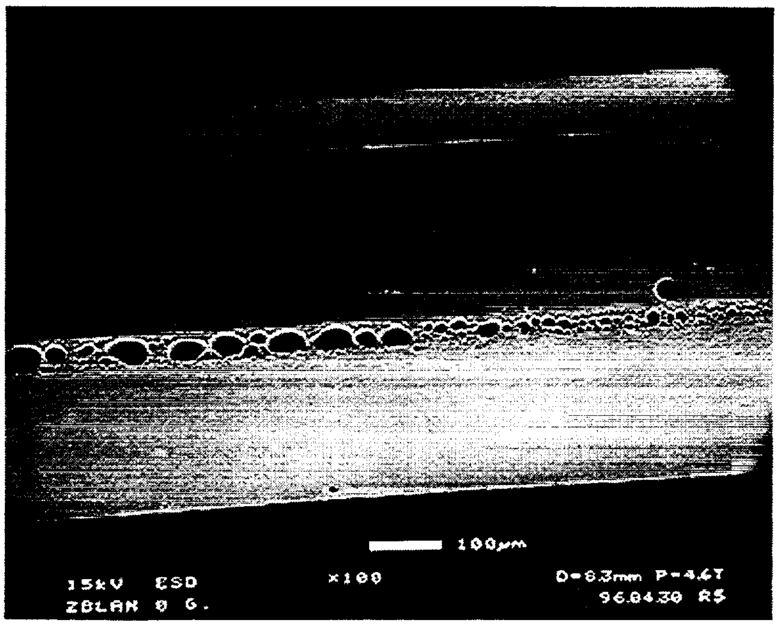


Figure 21. Micro-gravity processed ZBLAN sample.

The absence of crystallization in the samples flown at the pulling temperature is not unexpected based upon past flight experience. The authors have noted absence of crystallization after KC-135 flights when samples were heated to the crystallization temperature. The findings were previously noted by Canadian researchers as well. The porosity noticed in the flight samples was always located where the ZBLAN was in contact with the quartz. This is due, probably, to the reaction of the ZBLAN fluorides with the SiO_2 of the ampoule.[6] The porosity can be seen in the electron micrograph shown in Figure 21 as a thin strip running parallel with the length of the fiber. This has been observed in past flight and ground samples as well

4.1 Ground Results

After returning from White Sands the hardware was set up to process the ground samples and begin a detail analysis of the results. Figure 22 is of a ground processed sample with all conditions being the same as the flight with the exception of the gravity. Even though this sample was processed at the drawing temperature of only 340°C crystallites can easily be observed on the surface of the fiber.

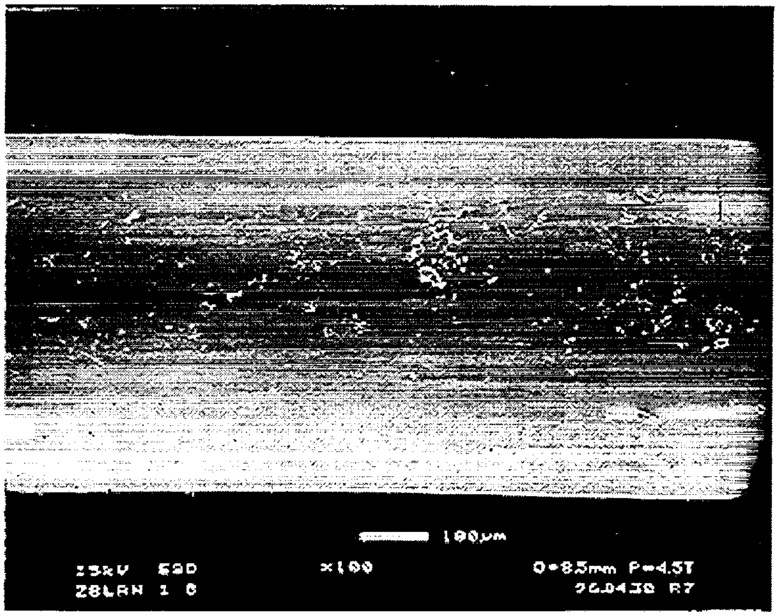


Figure 22. Ground processed ZBLAN sample analog to Figure 21.

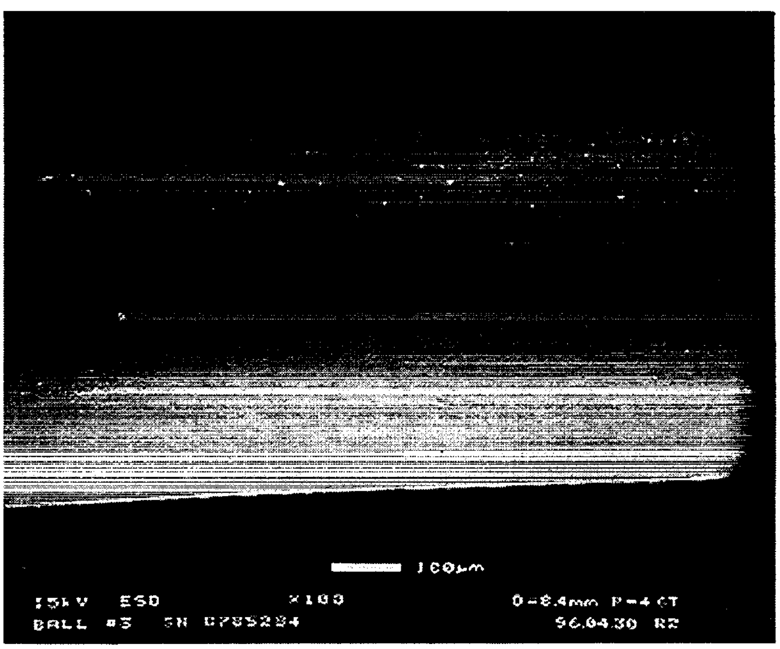


Figure 23. As received ZBLAN fiber sample.

The samples exposed to the quench water confirmed what other studies have shown; that ZBLAN is readily attacked when exposed to water.[7,8,9] The rate of dissolution increases rapidly with increasing temperature on the sample whether in microgravity or normal gravity.

The lack of crystallization in microgravity versus crystallization during 1g processing is somewhat puzzling. Thermodynamics and kinetics would indicate that crystal growth should occur regardless of the gravity. However the evidence indicates the contrary. It is believed that at 1-g there is enough solutal convection occurring to enhance crystallization. During microgravity the convection would be suppressed and thereby precluding crystallization. Work continues to determine the reason for this.

Figure 23 provides a view of what an "as received" ZBLAN fiber looks like. The outer protective coating has been removed. The white specks located on the surface of the fiber are surface imperfections and microcrystallites formed during the drawing process. All of the samples, both ground and flight, had similar morphology.

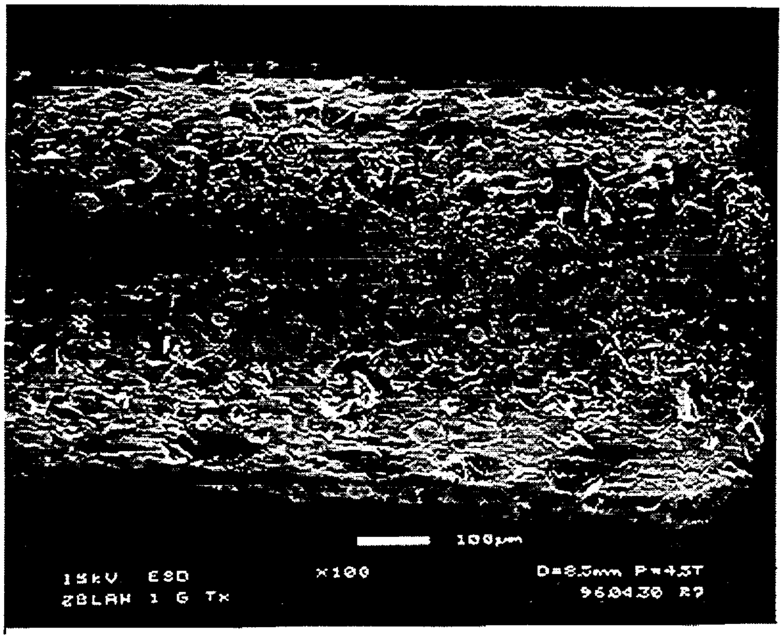


Figure 24. Ground sample processed at 374°C (T_x)

Figure 24 is a 100X magnification SEM of a ground processed ZBLAN fiber that was heated to the peak crystallization temperature of 374°C. The soak time was five minutes. Notice the much greater degree of crystallization on the surface of the fiber.

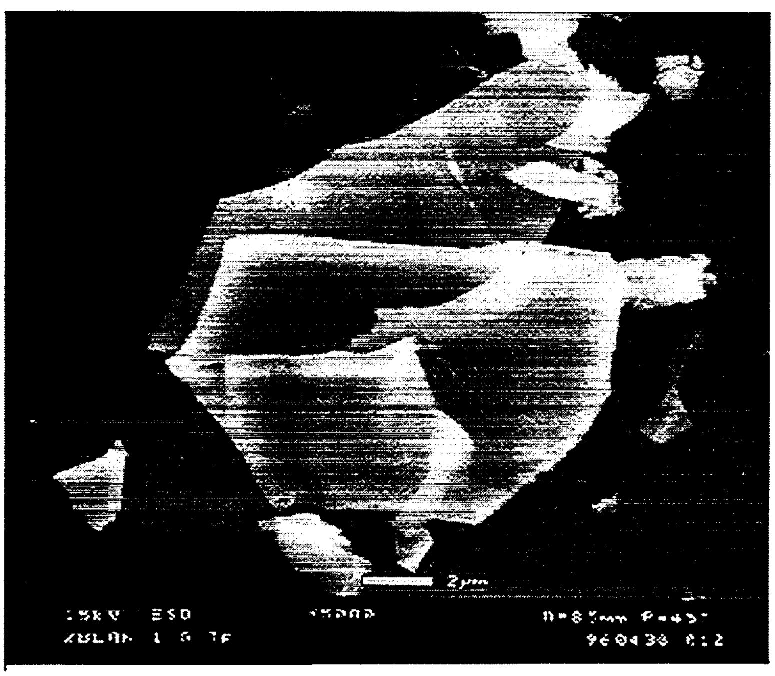


Figure 25. Close-up view of a surface crystal.

Figure 25 is a 5000X magnification of a surface crystal. EDX spectrum of these crystals indicates a high barium content as compared to a microgravity sample. Metastable and stable phases of beta-$BaZrF_6$ and beta-$BaZrF_{10}$ have been identified by other authors.[10,11]

5.0 Lessons Learned and the Future

In the field of research, especially when a hardware item is built and flown for the first time, one can always look back and see areas that could be improved upon. This project was no exception, all be it the hardware did perform as anticipated. This was a particularly difficult project since everyone associated with it had never been involved in anything like this before. Starting off as novices and then 7 months later successfully launching and operateing an experiment 175 miles into space is no minor accomplishment by anyone's standards. The following lists four improvements to the hardware that should be implemented before (and if) this hardware is ever flown again.

5.1 Ampoule design

Perhaps the most important lesson learned is with regards to the sample ampoule design. A thin walled quartz tube was chosen in order to make the sample heat up and cool down as quickly as possible. We now know that a thicker wall tubing probably would have prevented most, if not all, of the ampoule breakage during re-entry loads. Testing was conducted during three separate vibration runs on the hardware with the thin walled ampoules in place. The first vibration test on December 14 was to 19 g's in all three axes. The second and third tests were 12 g's. After each test the ampoules were inspected and there was never a single failure. Based on those results, we felt confident the ampoules would survive the flight. One explanation as to why the nine ampoules failed during the flight has been proposed. It is believed that while the ampoules were about half of an inch from completing the retraction into the quench assembly a lateral g spike caused the ampoules to impact the brass aperture located at the top of each quench sponge. This large g-spike occurred, probably, during the deployment of the parachute. While the results we did obtain confirmed previous results obtained from the KC-135, and research from others, more would have, of course, been better.

5.2 Stepper motor control

During the ground testing of the hardware at White Sands, it was determined that under certain conditions the stepper motor would false trigger and begin translating the samples into the heater assembly. If the countdown procedure had not been followed precisely on April 3 and a false trigger caused the stepper to activate prior to launch, then the experiment would have been lost. This is due to the fact that at present there is no way to control the stepper from within the block house. The false triggering was due to a ground loop problem between the laptop computer and the ground power supply. To prevent this from happening on a possible future mission the following should be implemented. The addition of microswitches to provide a "HOME" and "END OF TRAVEL" position sense of the sample translation plate would provide a more reliable starting and stopping point for the controller. In addition, a minor software modification would allow the stepper controller to be monitored and commanded by remote control. This would also make sample installation easier by eliminating the need to manually adjust the sample translation plate up and down.

5.3 Water pump motors

After reviewing the accelerometer data, it could be clearly seen that there were vibrations caused while the pumps were activated during the twenty second time period. This was due to the fact that the pumps were powered with the full 28VDC from the battery. It now is clear the supply voltage should have been reduced to about half and simply run the pumps for a longer time period. By running the pumps at half speed the vibrations they caused would have been reduced significantly. The operating voltage range for these models is from 8 to 28 volts. If there is ever a second flight, the wiring could be easily modified to power the pumps in series with each other or maintain the parallel wiring and add a dropping resistor to each pump motor to keep the reliability high.

5.4 Thermocouple signal conditioning

To amplify the thermocouple signals for the A/D board, Analog Devices model AD595 thermocouple signal amplifiers were used. These single chip devices provided a 10 millivolt per degree C output. Their only problem is that they do not provide any signal isolation. As a result, when the rocket was launched and the normal earth ground was lost, some of the thermocouples located in the heater cores developed a floating charge build up. As a result, the recorded signal had a bias error associated with it which had to be subtracted out. When operating the experiment on the ground, this problem does not appear. The only way to solve this problem completely is to have signal isolation between each thermocouple and the A/D board in the flight computer. Part of the problem also resides in the A/D's mutiplexer chip with crosstalk adding to the problem. This is inherent in the A/D board's design and can not be changed.

Correcting this problem represents the single most expensive modication presented so far. Incorporting signal isolation involves new thermocouple amplifier modules and the space required to mount them within the ZBLAN experiment envelope. Considerable new wiring and other integration processes would be required to complete the modification.

6.0 List of Deliverables to MSFC

Conclusion of this project resulted when the experiment hardware was delivered to Dr. Dennis Tucker of the Space Science Laboratory at the Marshall Space Flight Center. The items include the following:

1. Front Payload Mounting Plate with associated mounted hardware.
2. Rear Payload Mounting Plate with associated mounted hardware.
3. One baseplate support stand for the flight system.
4. Lexan cylinder cover for the assembled flight hardware.
5. One spare 28 VDC, 8 amp hour NiCd battery pack.
6. Ground interface box labeled as "ZBLAN GSE".
7. One box of miscellaneous spare parts including the sample holders.

To operate and download the data from the experiment a PC or laptop running a terminal emulation program (i.e. Procom) is required. For this project, a UAH owned laptop served this function. In addition a 28VDC, 15 amp power supply was used to supply the GSE power during ground operations. It is very important that if the experiment is turned on and, as result, the battery latch-in relay is closed, the only way to power down the system is either by removing the battery fuses or by using the software command to open the latching relay. To recharge the battery pack a 40VDC, 1 amp power supply with current limiting is required. A charge rate of 800 ma at 40 VDC for 15 hours is required for recharging an exhausted pack.

7.0 Acknowledgments

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In addition, we recognize the valuable assistance from Wayne Thompson for his development of the thermocouple signal conditioners, Bob Mattes for his help on the I/O control circuits, David Purves for his development of the software and April Monk for her general assistance.

Finally, we must extend our high regards to the UAH Machine Shop, not only for fabricating the parts needed for ZBLAN, but also for their valuable assistance and experience in designing flight hardware. Without their dedication this hardware could not have been built in as little time as it was, and for that we are grateful.

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